Heavy Flavor Production at the Tevatron

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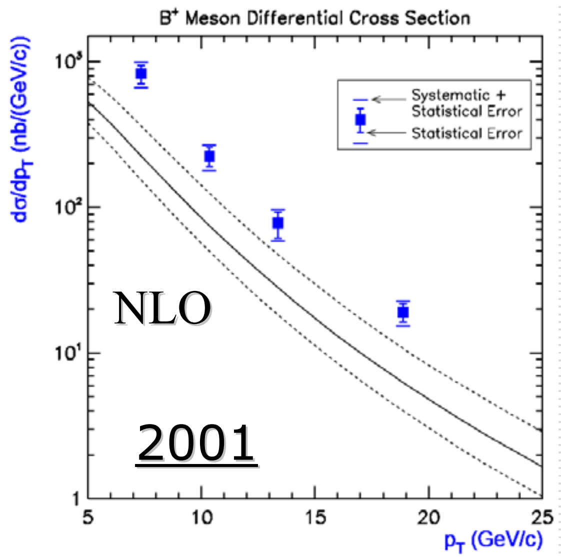
International Conference on High Energy Physics

July 26 - August 2, 2006

Moscow, Russia

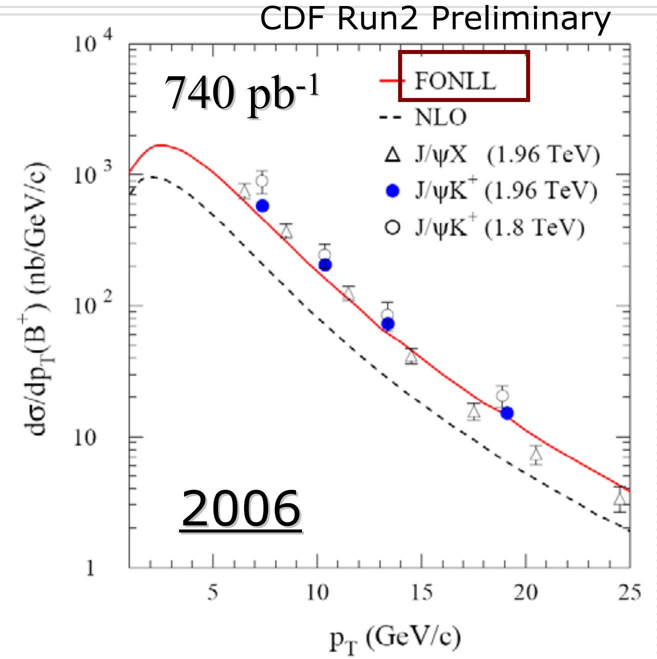
Heavy flavor production

- Studies of events containing *b*-quarks produced a variety of important physics results at the Tevatron:
  - Top quark discovery, measurements of top quark properties.
  - Various B physics: Spectroscopy, Lifetime measurement, Bs mixing, etc



- However, understanding *b* production has been a big challenge in QCD.
  - >20 years after the discovery of the *b*-quark (1977), the measured *b* cross section was still >2 x larger than predictions.
  - Only recently, data and theory started to agree:
    Fixed order + NLL (FONLL), improved fragmentation function, …

- Further understanding *b* production (especially *b*-quark jet) will enhance the potential for discoveries of new physics.
  - QCD heavy flavor production is important background in many new physics searches



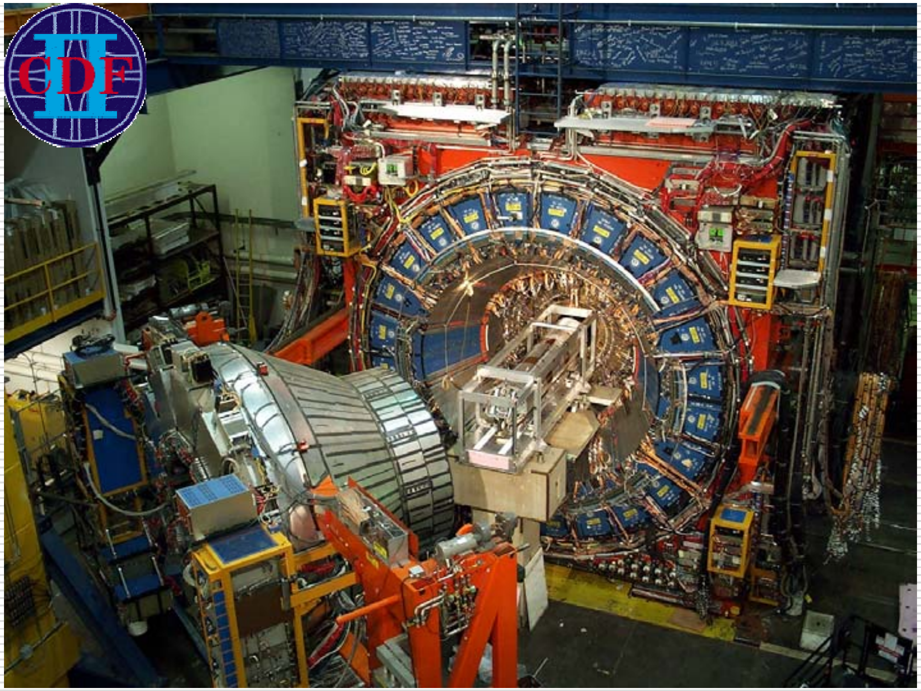
New CDF B^+ measurement included

Outline

- Introduction
- Inclusive *b*-jet production
  - cross section measurement
  - *b*-jet shape
- $Z + b$-jet production
- $W + b\bar{b}$ production
- Conclusions

Photon + *b*-jet measurement was presented in the Ch. Schwanenberger's talk on Thursday.

Tevatron Run 2 detectors

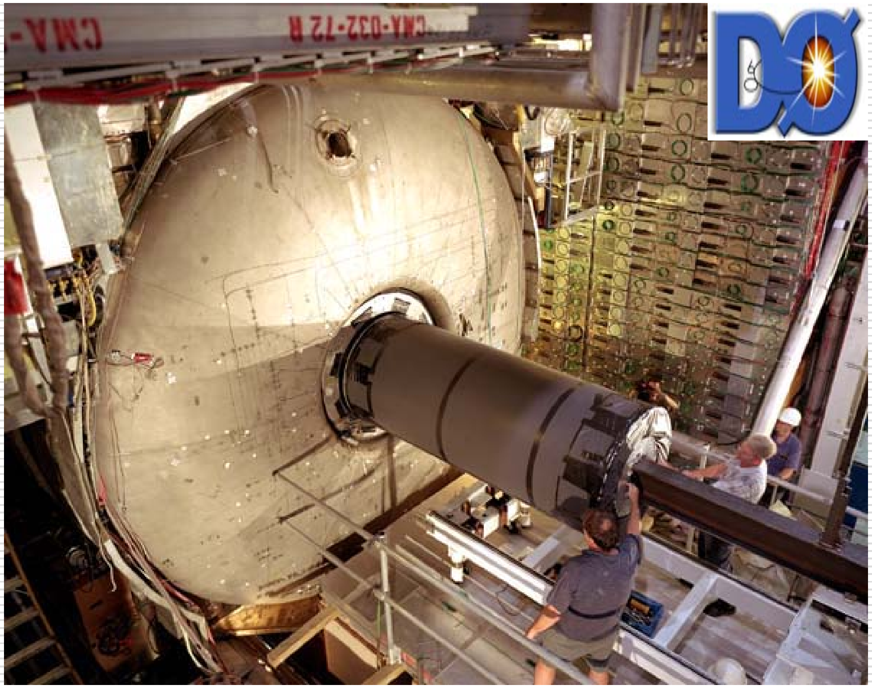


Both detectors are the general-purpose detectors:

- Silicon microvertex detector
- Solenoid
- Muon chambers
- Calorimeter ⟶ Measuring jets

identifying *b*-quarks

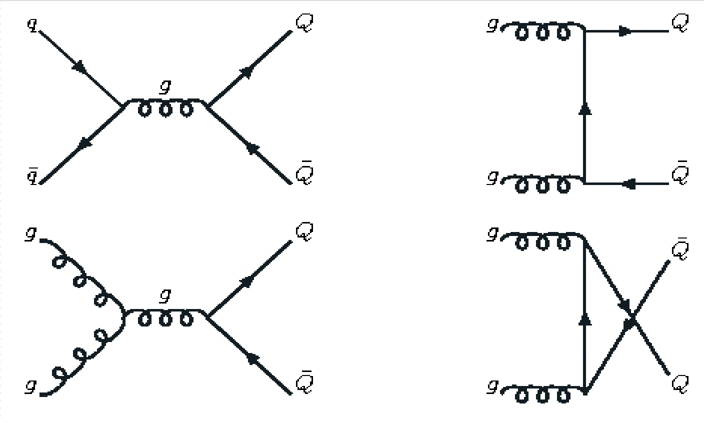
Excellent tracking resolution



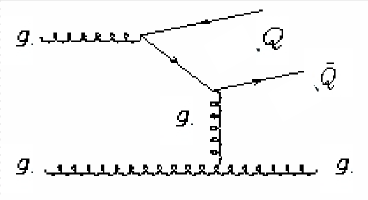
Excellent muon identification and acceptance

Inclusive *b*-jet production

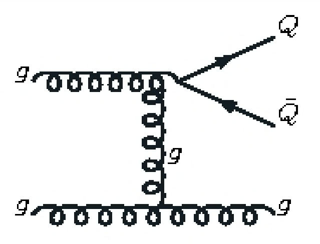
b-quark production at hadron colliders



Leading order processes



Flavor excitation



Gluon splitting

+ ……

Next-to-leading order processes

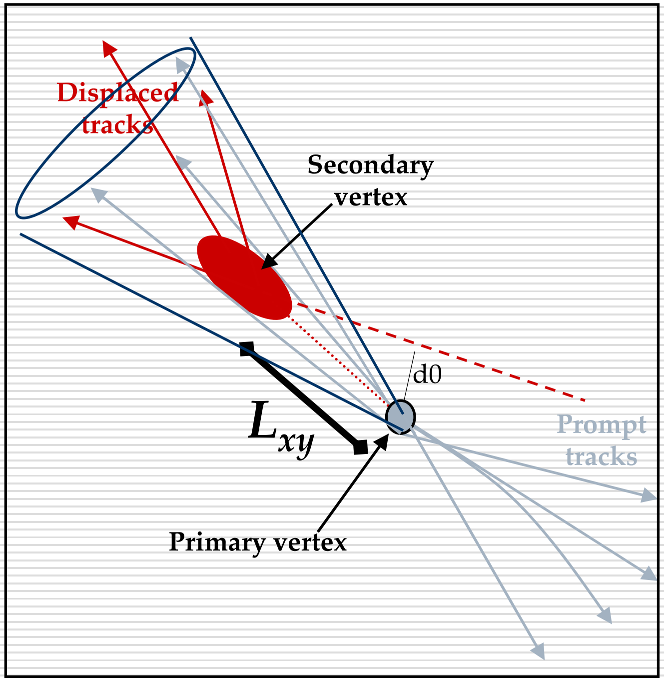
Experiments measure either *B* hadrons or *b*-jets.

Measurement of *b*-jets:

- *b*-jets contain most of *b* remnants: less sensitive to the fragmentation function
- Wide Pt region: in high Pt physics, experiments find *b*-quarks through *b*-jets

b-jet identification

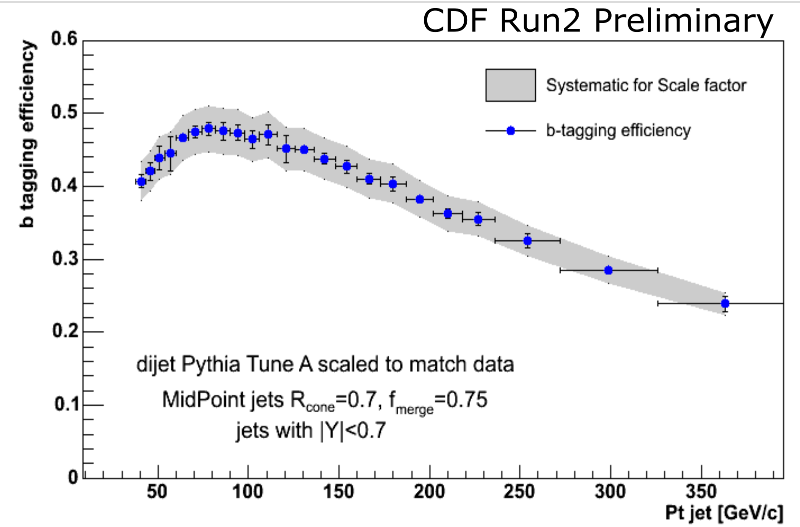
- The most commonly used "tagging" technique identifies *b*-jets with a displaced secondary vertex (long *B* hadron lifetime, cτ ~ 450 μm)
  - consider tracks in η-φ cone of 0.4 around jet axis
  - reconstruct secondary vertex from displaced tracks
  - If the vertex has large transverse displacement (Lxy), the jet is "*b*-tagged".



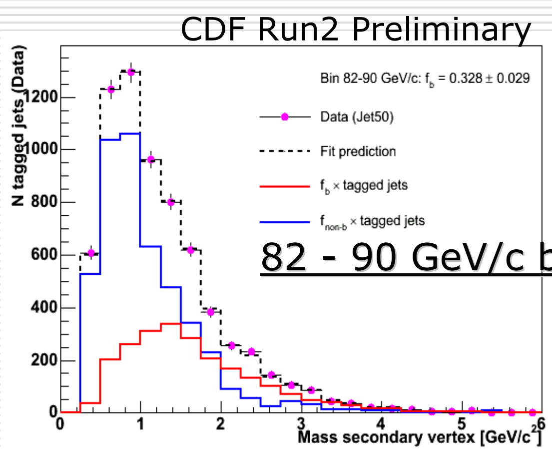
- Evaluate *b*-tagging performance:
  - Tag efficiency for *b*-jets
  - *b*-fraction: fraction of *b's* in the tagged sample

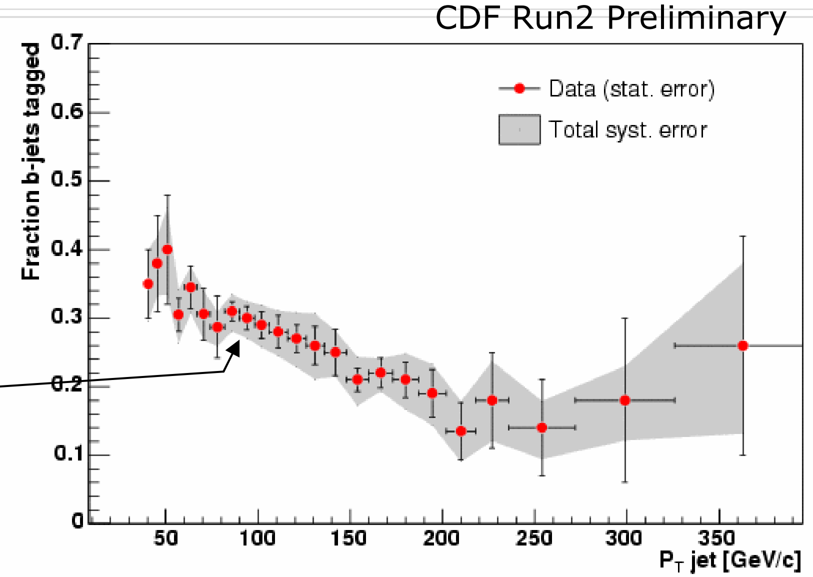
b-jet identification: CDF

- *b*-tag efficiency:
  - From MC to cover wide jet Pt
  - Correct for the data-MC difference due to simulation imperfections: $\varepsilon^{data} / \varepsilon^{MC} = 0.91 \pm 0.06$.

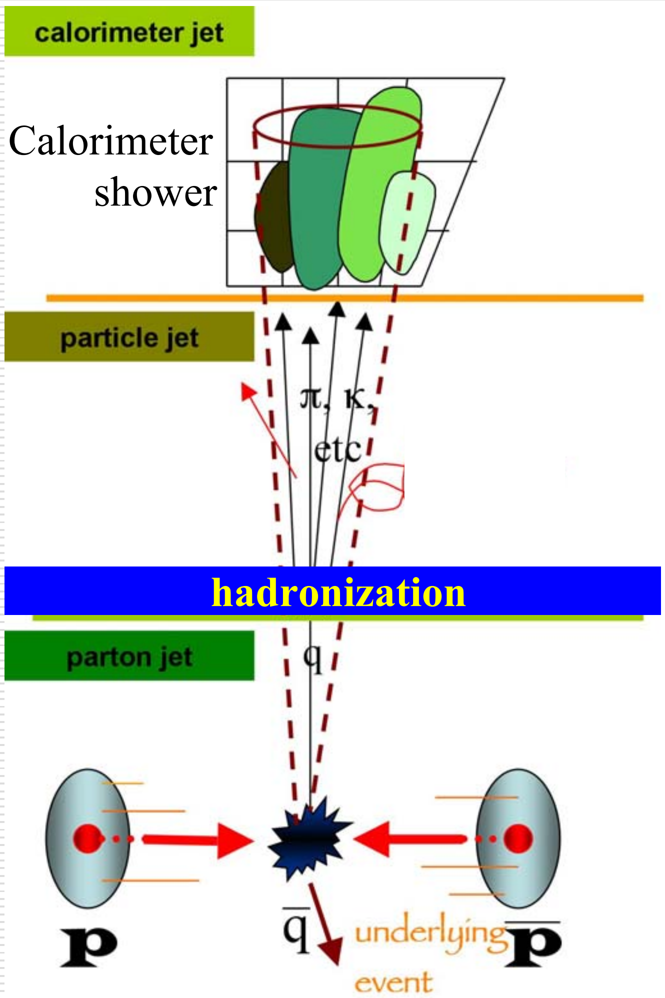


- *b*-fraction:
  - Make template fits to the secondary vertex mass distributions: *b*-jet has larger secondary vertex mass (large B-hadron mass)
  - The fit is made in each jet Pt bin.





Jet energy corrections: CDF



Jet energies measured by the calorimeters have to be corrected before compared to theoretical predictions.

- Energy from pile-up events ← Correction from data
- Average energy loss of jets due to the non-compensating nature of the calorimeter
- Smearing (resolution) effect

Correction from simulated *b*-jets. Individual particle response in simulation tuned to test-beam and in-situ data.

⇓

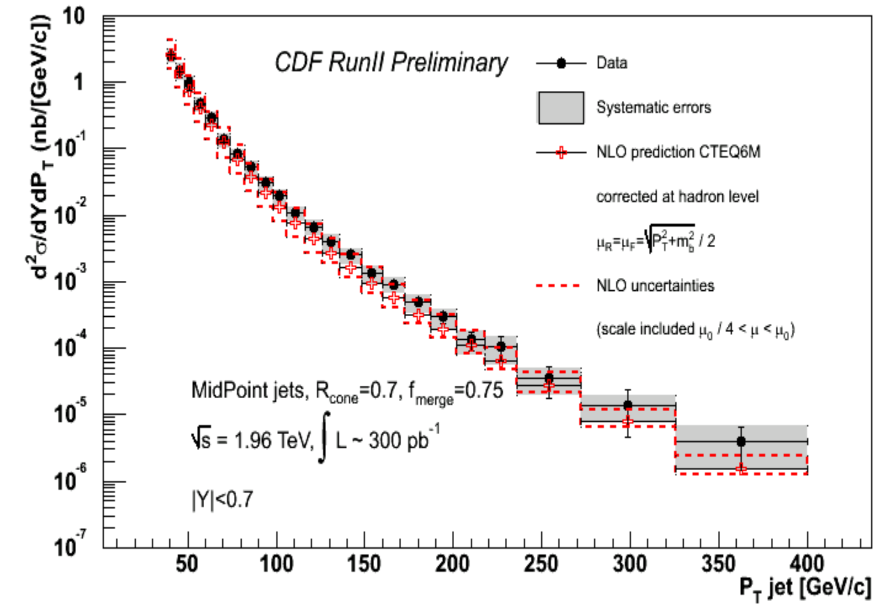
Hadron-level cross section

To make fair comparisons with parton-level pQCD predictions, need to account for:

- Underlying event
- Hadronization

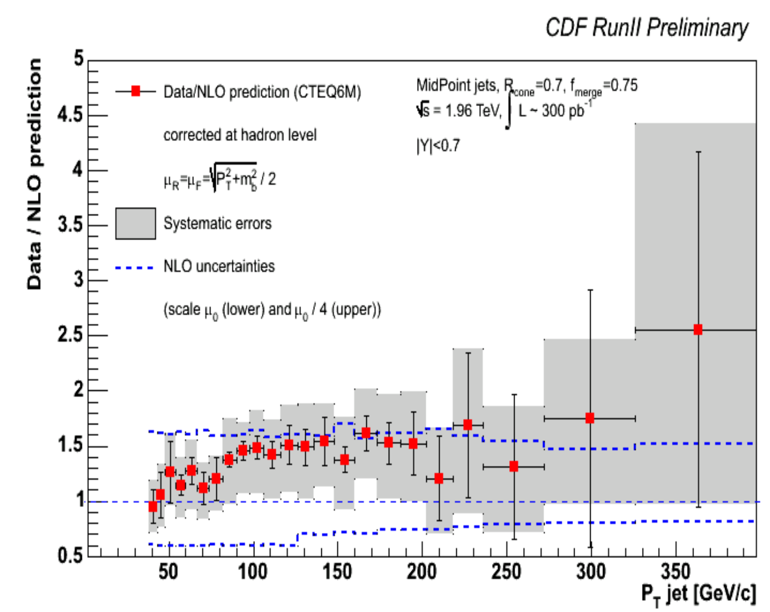
Effects evaluated from simulated *b*-jet events. Underlying event in MC is tuned to data.

Inclusive *b*-jet cross section: CDF



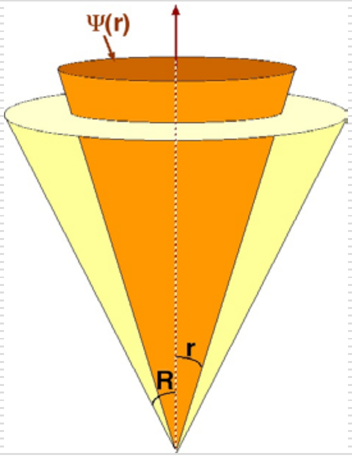
- Measurement covers up to 400 GeV/c in Pt, more than 6 orders of magnitude in cross section
- Main experimental uncertainties:
  - jet energy scale
  - *b*-fraction in the tagged sample

- NLO prediction uncertainties are mainly from μ scales
- Agreement with NLO pQCD predictions based on CTEQ6 PDF within uncertainties

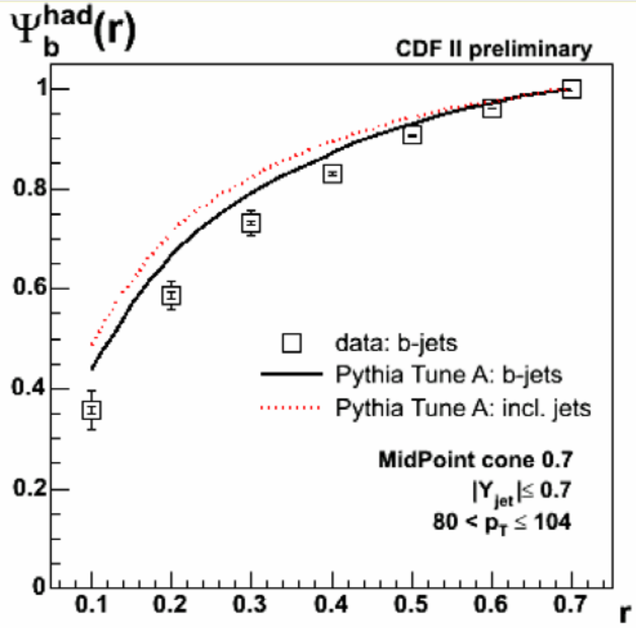


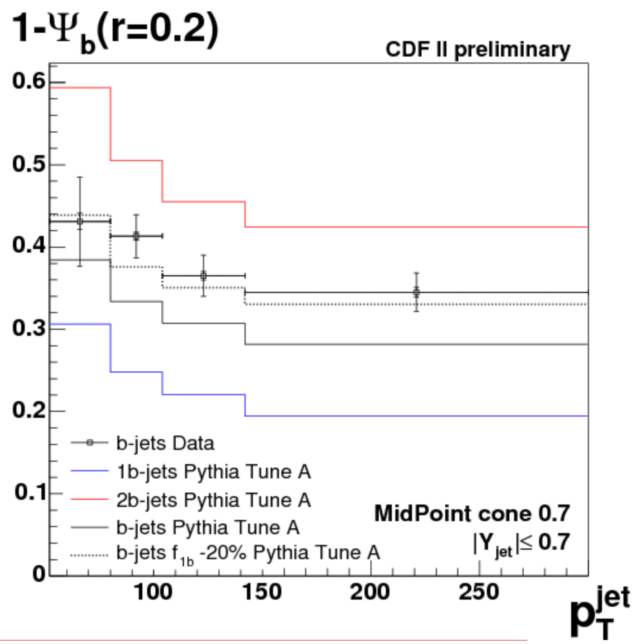
b-jet shape: CDF

$$\Psi(r) = \int_0^r \frac{p_T(r')}{p_T^{jet}} dr' = \frac{1}{N_{jets}} \sum_{jets} \frac{p_T(0,r)}{p_T(0,R)}$$



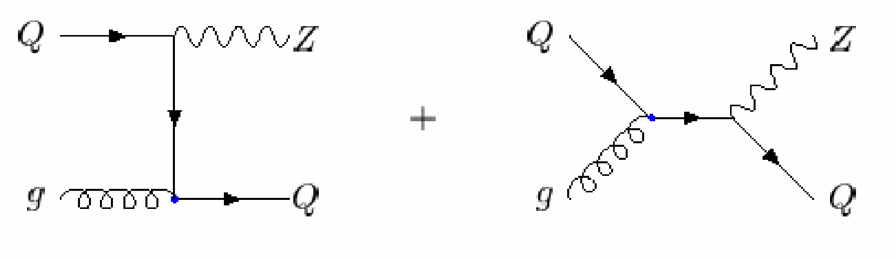
- *b*-jet shape measured for jet Pt from 52 to 300 GeV/c
- *b*-jets measured to be wider than inclusive jets
- Agreement with PYTHIA is poor
  - Jet shape strongly depends on # of *b*'s in the jet.
  - The agreement is better when the ratio of jets with 1- to 2-*b*'s in PYTHIA is decreased by 20%
- Comparisons with other MCs in progress





Z + *b*-jet production

Probe the less-well-known heavy flavor content of the proton.



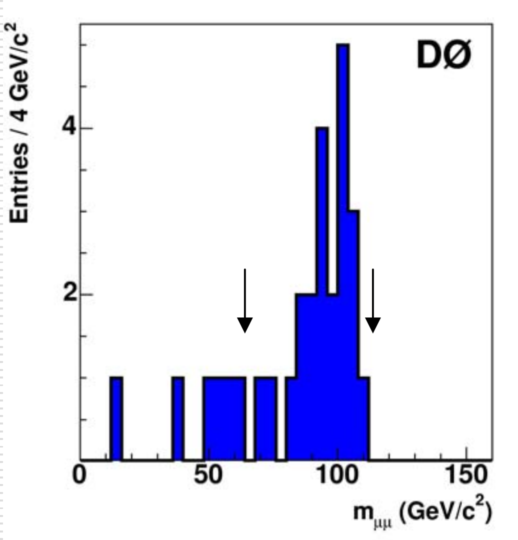
The knowledge of the *b*-density in the proton influences:

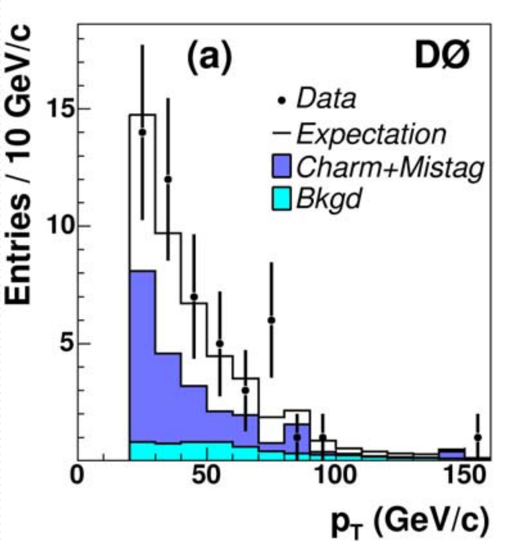
- Single top-quark production $qb \rightarrow q't$ and $gb \rightarrow Wt$
- Supersymmetric higgs boson production, $gb \rightarrow hb, bb \rightarrow h$

Major background for SM higgs searches $(ZH, H \rightarrow b\bar{b})$

Z + *b*-jet production: DØ

- Z events selected with di-leptons (ee and μμ).
- *b*-jet identification similar to the CDF inclusive *b*-jet measurement.





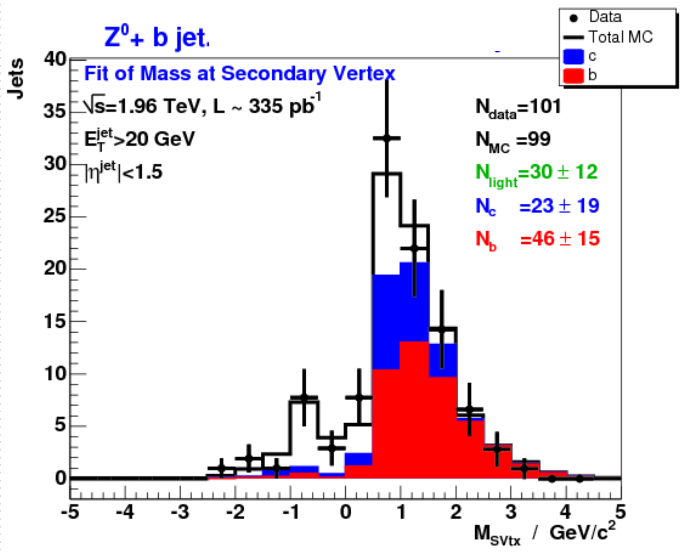
- σ(Z+*b*-jets) / σ(Z+jets) is measured to be:

$$\boxed{2.1 \pm 0.4(\text{stat})^{+0.2}_{-0.3}(\text{syst})\,\%} \quad (p_T^{jet} > 20\,\text{GeV/c and } |\eta^{jet}| < 2.5)$$

- In agreement with the next-to-leading order (NLO) prediction 1.8 ± 0.4 % based on CTEQ6 PDF.

Z + *b*-jet production: CDF

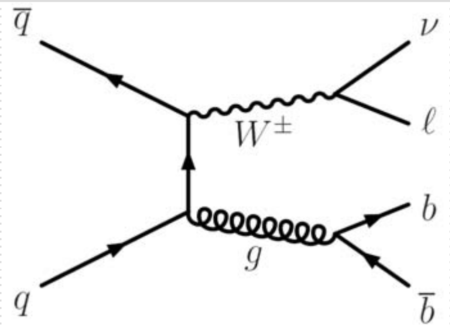
No assumption made on σ(Z+*c*-jet)/ σ(Z+*b*-jet): the fraction determined from the template fit of the secondary vertex mass distributions.

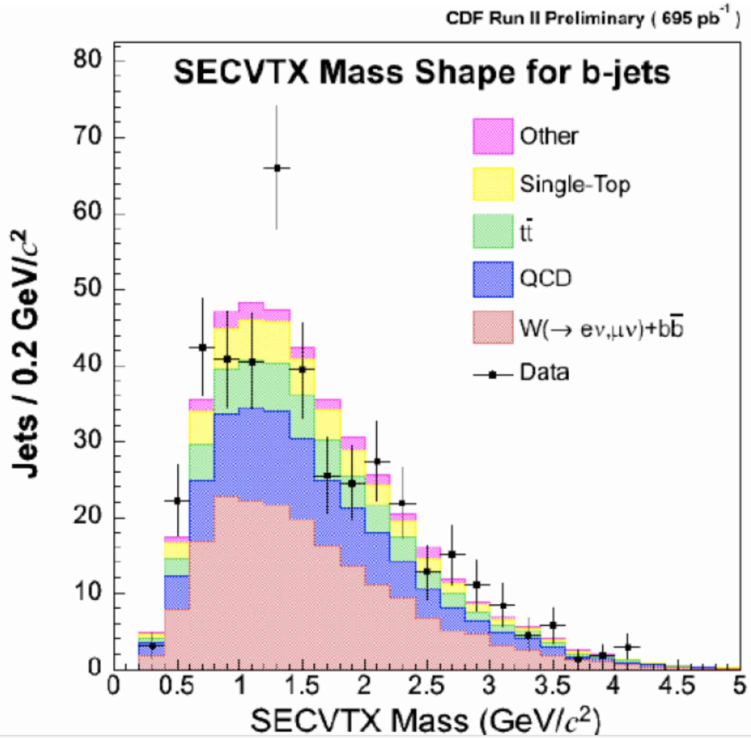


E_T^{jet}>20 GeV, $|\eta^{jet}|$<1.5 R_{jet}=0.7	CDF measurement	PYTHIA	NLO (MCFM, CTEQ6)
σ(Z+*b*-jet)	0.93 ± 0.29 ± 0.21 (pb)		0.45 ± 0.07 (pb)
σ(Z+*b*-jet)/ σ(Z)	0. 37 ± 0.11 ± 0.08 %	0.35 %	0.19 ± 0.03 %
σ(Z+*b*-jet)/ σ(Z+jet)	2.36 ± 0.74 ± 0.53 %	2.18 %	1.81 ± 0.27 %

Consistent with NLO within errors, however statistically limited.

$Wb\bar{b}$ production: CDF





Large background for many analyses

- SM Higgs (WH) production
- Single top quark production
- $t\bar{t}$ production

$$\boxed{\sigma(W^{\pm}b\bar{b}) \times BR(W^{\pm} \to l^{\pm}\nu) = 0.90 \pm 0.20(\text{stat.}) \pm 0.26(\text{syst.})\ \text{pb}}$$

$(E_T > 20\,\text{GeV}, |\eta| < 2)$

Consistent with Alpgen (0.74±0.18pb) within errors. No NLO comparison yet.

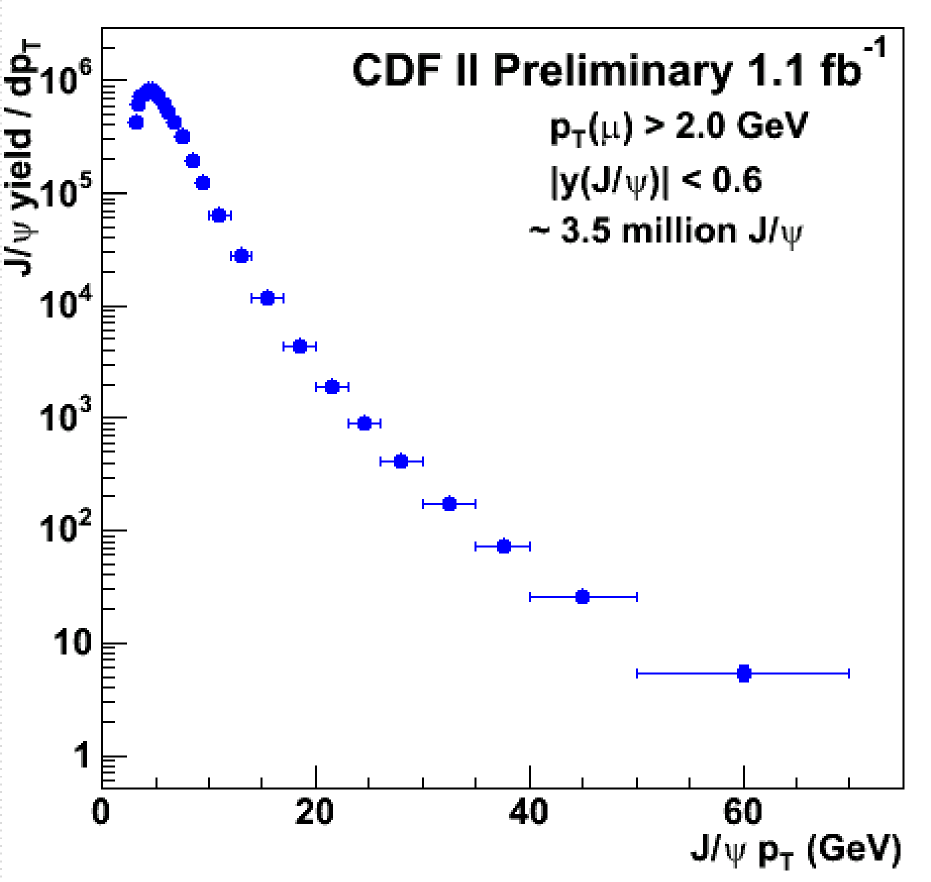
Conclusions

- Big effort has been made on studies of heavy quark production at the Tevatron in Run 2
- Measurements of inclusive *b*-jet cross section by CDF and Z+*b*-jet cross section by CDF and DØ
  - Results are in agreement with NLO pQCD predictions
  - Z+*b*-jet measurements limited by statistics. >2 x data are already in our hands.
- Measurement of *b*-jet shape by CDF
  - *b*-jets measured to be wider than inclusive jets
  - Agreement with PYTHIA is poor. Sensitive to fraction of jets containing 2 *b*'s.
- $Wb\bar{b}$ cross section measurement by CDF
  - Consistent with Alpgen prediction

Backup

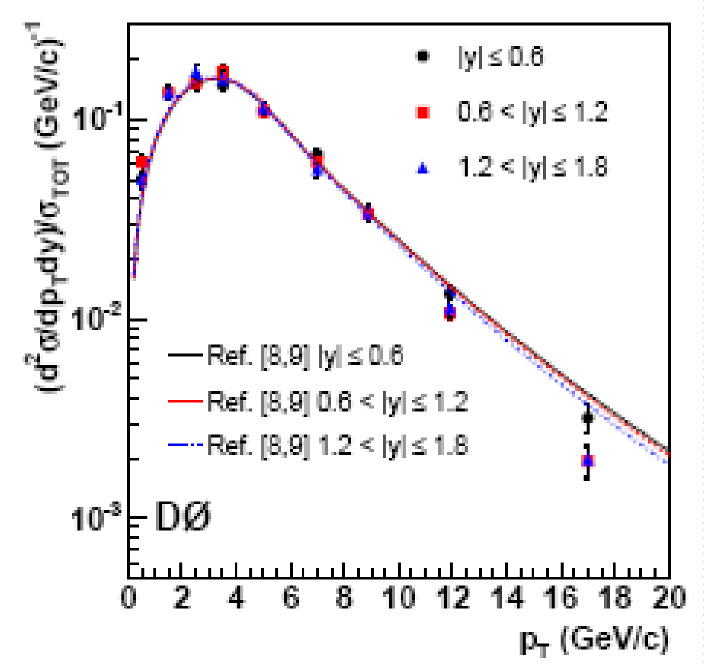
J/Ψ production: CDF

- Sizable number of J/Ψ's up to Pt = 60 GeV/c.
- Will allow us to extend the J/Ψ and *b* cross section measurement to higher Pt than before.
- Comparisons with *b*-jet measurements?



Υ(1S) production: DØ

- Bottomonium bound state production model depends on assumptions on the non-perturbative transition from the *bb* pair to a bottomonium.
- Color singlet model (CSM), color evaporation model, color octet model (COM)



Υ(1S) reconstructed from di-muons.

Rapidity range up to |y|<1.8, extended from the Run 1 CDF measurement.

Comparison to COM (hep-ph/0411026,0404158)

Further constraints on parameters of bottomonium production models

b-jet shape: CDF